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13. ABSTRACT *(Maximum 200 words)*
The effectiveness of intermittent, microclimate cooling for men who worked in U.S. Army chemical protective clothing (modified Mission Oriented Protective Posture level 3; MOPP 3) was examined. The hypothesis was that intermittent cooling on a 2 min on-off schedule using a liquid cooling garment (LCG) covering 72% of the body surface area would reduce heat strain comparably to constant cooling. Four male subjects completed three experiments at 30°C, 30% relative humidity wearing the LCG under the MOPP 3 during 80 minutes of treadmill walking at 224±5 Wom-2. Water temperature to the LCG was held constant at 21°C. The experiments were: 1) constant cooling (CC); 2) intermittent cooling at 2-min intervals (IC); 3) no cooling (NC). Core temperature increased (1.6 0.2°C) in NC, which was greater than IC (0.5 0.2°C) and CC (0.5 0.3°C) ($p<0.05$). Mean skin temperature was higher during NC (36.1 0.4°C) than IC (33.7 0.6°C) and CC (32.6 0.6°C), and mean skin temperature was higher during IC than CC ($p<0.05$). Mean heart rate during NC (139 9 bomin-1) was greater than IC (110 10 bomin-1) and CC (107 9 bomin-1) ($p<0.05$). Cooling by conduction (K) during NC (94±4 Wom-2) was lower than IC (142±7 Wom-2) and CC (146±4 Wom-2) ($p<0.05$). These findings suggest that IC provided a favorable skin to LCG gradient for heat dissipation by conduction and reduced heat strain comparable to CC during exercise-heat stress in chemical protective clothing.

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Intermittent microclimate cooling during exercise-heat stress in US army chemical protective clothing

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The effectiveness of intermittent, microclimate cooling for men who worked in US Army chemical protective clothing (modified mission-oriented protective posture level 3; MOPP 3) was examined. The hypothesis was that intermittent cooling on a 2 min on–off schedule using a liquid cooling garment (LCG) covering 72% of the body surface area would reduce heat strain comparably to constant cooling. Four male subjects completed three experiments at 30°C, 30% relative humidity wearing the LCG under the MOPP 3 during 80 min of treadmill walking at 224 ± 5 W $\cdot$ m^{-2}. Water temperature to the LCG was held constant at 21°C. The experiments were; 1) constant cooling (CC); 2) intermittent cooling at 2-min intervals (IC); 3) no cooling (NC). Core temperature increased (1.6 ± 0.2°C) in NC, which was greater than IC (0.5 ± 0.2°C) and CC (0.5 ± 0.3°C) ($p < 0.05$). Mean skin temperature was higher during NC (36.1 ± 0.4°C) than IC (33.7 ± 0.6°C) and CC (32.6 ± 0.6°C) and mean skin temperature was higher during IC than CC ($p < 0.05$). Mean heart rate during NC (139 ± 9 b $\cdot$ min^{-1}) was greater than IC (110 ± 10 b $\cdot$ min^{-1}) and CC (107 ± 9 b $\cdot$ min^{-1}) ($p < 0.05$). Cooling by conduction (K) during NC (94 ± 4 W $\cdot$ m^{-2}) was lower than IC (142 ± 7 W $\cdot$ m^{-2}) and CC (146 ± 4 W $\cdot$ m^{-2}) ($p < 0.05$). These findings suggest that IC provided a favourable skin to LCG gradient for heat dissipation by conduction and reduced heat strain comparable to CC during exercise-heat stress in chemical protective clothing.

Keywords: Personal cooling; Heat strain; Chemical protective clothing; Human

1. Introduction

Numerous civilian and military occupations, including first response teams, fire fighting, and hazardous materials (HAZMAT) clean-up, require personnel to work in

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contaminated environments wearing environmental protective clothing. The protective clothing required for these situations ranges from semi-permeable chemical protective uniforms to fully encapsulating impermeable level A HAZMAT systems providing protection from contamination through the skin and/or the respiratory tract. The microenvironment created by protective clothing has minimal capability for heat dissipation through conduction, radiation, convection and, most importantly, evaporation of sweat (Speckman *et al.* 1988). The end result is reduced work due to elevated heat strain (Goldman 1963, Henane *et al.* 1979, Mihal 1981, Speckman *et al.* 1988).

Personal microclimate cooling systems (MCC) reduce heat storage and enhance work performance (Nunneley 1970, Speckman *et al.* 1988, Cadarette *et al.* 1990, 2001, 2002). Current civilian and military MCC provide cooling under the protective clothing in one of three ways: 1) ice packs; 2) cooled, filtered air blown from a torso vest; or 3) circulating liquid cooled garments (LCG) worn in varied configurations (i.e. whole body, upper body only, or torso vest only). The ability of circulating LCG systems to reduce the level of heat strain improves as the surface area covered by the LCG is increased (Speckman *et al.* 1988, Cadarette *et al.* 2002). The US Army primarily uses either ice pack cooled or vapour compression cooled LCG MCC for soldiers in semi-permeable HAZMAT chemical protective clothing. Both systems deliver cooled water at constant flow rates. The ice-based systems deliver cooled liquid at approximately 8–12°C, dependent on ambient temperature, whilst currently fielded vapour compression systems deliver liquid at approximately 17°C in a 37.8°C environment.

The application of intermittent regional cooling (IRC) was recently examined during exercise (Cheuvront *et al.* 2003). Cooling was provided to four body regions (legs, back, chest, head) in one of five paradigms; one segment at a time for either 1 min each or 2 min each, two segments at a time (legs/back and chest/head) for either 2 min each or 4 min each, and all regions continuously. All four IRC paradigms reduced cardiovascular and thermoregulatory strain relative to no cooling (NC), and all four were comparable to constant cooling (CC; Cheuvront *et al.* 2003).

The cooling paradigms in that study required a sophisticated control system using multiple valves and pumps. It remains unknown whether a less sophisticated intermittent cooling (IC) system with a simple on/off sequence would be as effective. This study was conducted to examine that question. It was hypothesized that simple IC to the entire LCG for 50% of the time in a 2 min on/off cycle would attenuate the rise in core temperature as effectively as CC during exercise. The rationale for this hypothesis was that CC at 21°C lowers skin temperature to a level that causes peripheral vasoconstriction and increases the insulative layer between the body's core and the fluid circulating in the LCG. This slows the rate of heat removal (Johnson *et al.* 1976). IC with a simple on/off control sequence might be just as advantageous in inducing periods without vasoconstriction and perhaps slight cutaneous vasodilation with higher skin temperatures. This would provide a favourable gradient for heat removal, as previously demonstrated (Cheuvront *et al.* 2003).

The results of the study by Cheuvront *et al.* (2003) indicated that IRC applied sequentially to different body regions reduced cardiovascular and thermoregulatory strain comparable to CC without reducing skin temperatures to levels causing vasoconstriction. The current study suggests the possibility that a simply designed on–off IC scenario would prove as effective as the sequential regional cooling system. Providing cooling on an on–off intermittent basis might allow for the use of lighter weight or smaller motors, pumps or heat exchangers. In addition, the fact that the pump would run only half as often might mean that a smaller battery could be used for a given length of work. These changes should result in both a less complicated system design and a reduced weight to be carried by the user.

The IC scenario used in the current study was based on the premise that running a vapour compression system (for liquid cooling) for only one-half as long might reduce battery requirements and allow for a simple cooling system design. While using this scenario would allow for a more simplified refrigeration system, it would also result in the entire system heating up during the off phase of the cycle compared to the sequentially cooled system, which is always on. In this case, water returning to the refrigeration unit could not be chilled as rapidly during the initial portion of the on phase, reducing the transfer of heat from the body to the circulating water. This limitation suggests that the sequential approach to IC reported by Cheuvront *et al.* (2003) might still provide the most efficient means of body cooling. This method would require a more intricate design, but might still reduce weight and power requirements when compared to a constant flow of chilled liquid to the entire LCG. Pumps and heat exchangers could be smaller as they would handle a lower flow rate each minute from the individual regions.

2. Methods and materials

2.1. *Subjects*

Four healthy male volunteers served as test subjects after being medically cleared to participate in the research. The subjects were fully informed of the purpose, procedures and potential risks of the study and signed a statement of informed consent. The appropriate Institutional Review Boards approved the study, the investigators adhered to the policies for protection of human subjects as prescribed in Army Regulation 70–25, and the research was conducted in adherence with the provisions of 45 CFR 46. Descriptive characteristics of the subjects (mean $\pm$ SD) were age (26 ± 9 years), height (180 ± 4 cm), weight (80 ± 8 kg) and body surface area ($2.0 \pm 0.1\ m^2$). These subjects also participated in a previous IC study (Cheuvront *et al.* 2003).

2.2. *Procedures and measurements*

One week before experimental testing, subjects performed 5 d of heat familiarization in an environmental test chamber set at 35°C, 50% relative humidity. The subjects walked on a motor-driven treadmill at $1.36\ m \cdot s^{-1}$ and a 2% grade for 100 min (two repeats of 50-min exercise with a 10-min rest between) while wearing a t-shirt, shorts, socks and athletic shoes. Water intake was provided *ad libitum* during the entire exposure and subjects were rehydrated after exercise to within $\pm 1\%$ of initial body weight.

Experimental testing began each morning at 08.30 hours. Subjects arrived at the laboratory, drank a standard 120 ml water bolus and were weighed semi-nude after voiding and self-placement of a rectal thermistor approximately 10 cm beyond the anal sphincter. No further liquid ingestion was permitted until completion of the day's experiment. Subjects' skin thermistors (water bath calibrated at multiple temperatures) were placed on the right side of the body (head, upper back, lower back, chest, abdomen, forearm, thigh and calf), and three electrocardiogram (ECG) electrodes were attached.

Following instrumentation, subjects donned a three-piece LCG that covered the head (hood), torso (vest) and legs (pants). The LCG was worn in all tests including NC, as if it were part of a standard duty uniform. The LCG was stored at ambient test conditions to allow the water inside to reach equilibrium with room temperature before the garment was donned. The LCG design consisted of cotton or Nomex® aramid fabric woven or laminated around small diameter Tygon® tubing (2.5 mm, I.D.) divided into multiple parallel circuits. Total estimated tubing length for the ensemble was approximately 108 m. Total body surface area covered was 72% (head = 6%, torso = 22% and legs = 44%) as measured using a Cyberware® (Cyberware, Inc., Monterey, CA) three-dimensional head and whole body scanner. Following the LCG fitting, subjects dressed in the US Army mission-oriented protective posture chemical protective clothing system that included a charcoal-impregnated over-garment (top and bottom), cotton glove liners, butyl gloves and M-40 chemical–biological field mask with hood. The subjects wore personal athletic shoes to complete the clothing ensemble. Fully clothed body mass was recorded before the start of exercise.

All subjects completed three experiments in an environmental chamber (dry bulb temperature = 29.8 ± 0.4°C; dew point temperature = 10.9 ± 0.1°C (30% relative humidity)). They walked for 80 min on a treadmill at 1.36 $m \cdot s^{-1}$, 2% grade (metabolic rate of 224 ± 5 $W \cdot m^{-2}$). The three experimental conditions were; 1) CC to the LCG; 2) IC to the LCG circulated at a rate of 2 min on and 2 min off; 3) NC.

The three experimental conditions were tested in a balanced order. Inlet water temperature was maintained at 21°C to approximate the most common self-selected inlet water temperature for thermal comfort (Shitzer *et al.* 1973). Garments were connected to a temperature-controlled recirculating water bath (Neslab RTE-111, Newington, NH), and coolant was pumped through foam-insulated inlet/outlet umbilical tubes to the LCG at a rate of 1.2 $litre \cdot min^{-1}$. This flow rate and 3.5°C temperature gradient (based on limited data prior to a mechanical failure of the inline, outlet temperature thermistor) provided a theoretical heat removal expressed per unit of body surface area covered (%BSA) of 4.25 W per %BSA or approximately 305 W during constant flow. This value is similar to the measured cooling provided by a portable cooling system (head, torso and arms) designed for a military HAZMAT uniform system (Cadarette *et al.* 2002).

The three cooling conditions were programmed using Agilent VEE™ (Agilent Technologies, Inc., Palo Alto, CA) software to ensure that cooling cycles were identical with each subject. Output data were downloaded at approximately 5 s intervals to a data acquisition system for analysis. Mean weighted skin temperature ($\overline{T}_{sk}$) and core temperature (T_{re}) measurements were also compiled by the same data acquisition system at the same interval. Heart rate was obtained at 10-min intervals by ECG. Metabolic rate (M) was measured for a 4-min duration by open-circuit spirometry (PARVO Truemax 2400™, Salt Lake City, UT) during the last 5 min of the 80 min exercise period after removal of the protective mask and hood. Thermal balance data were analysed using only the first 75 min of exercise prior to removing the hood and mask. At the completion of exercise, body mass was again recorded both fully clothed and semi-nude for the determination of sweat loss and evaporative efficiency.

2.3. *Calculations*

$\overline{T}_{sk}$ was calculated by formula 1 from Gagge and Gonzalez (1996).

$$\begin{aligned}\overline{T}_{sk} = {} & 0.07T_{head} + 0.10T_{upper\ back} + 0.10T_{lower\ back} + 0.10T_{chest} \\ & + 0.10T_{abdomen} + 0.14T_{forearm} + 0.19T_{thigh} + 0.20T_{calf}\end{aligned} \tag{1}$$

Mean body temperature ($\overline{T}_b$) was calculated from T_{re} and $\overline{T}_{sk}$ by formula 2 where x is the appropriate weighting coefficient (0.8) for environments ranging from cold (Vallerand *et al.* 1992) to thermoneutral (Bittel 1987).

$$\overline{T}_b = xT_{re} + (1 - x)\,\overline{T}_{sk} \tag{2}$$

Heat removed by the LCG was calculated by using formula 3 to resolve the heat balance equation. The difference between heat production and heat loss was calculated using direct (or derived from direct) calorimetric and thermometric measurement techniques.

$$K = M \pm W \pm E_{res} \pm C_{res} \pm E_{cl} \pm (R + C) \pm S \tag{3}$$

K represents microclimate cooling by conduction, M is metabolic rate, W is the external work rate, E_{res} and C_{res} are the rates of latent (evaporative) and dry (convective) heat exchanges via the respiratory tract, respectively, E_{cl} and $(R + C)$ are the rates of evaporative and dry (radiant and convective) heat exchanges between clothed skin and the environment, and S is the rate of heat storage. All values ($W \cdot m^{-2}$) were calculated for clothed persons using calorimetric equations (Kolka *et al.* 1994, Gagge and Gonzalez 1996) with the exception of S, which required calculation by thermometry (Gagge and Gonzalez 1996) in order to resolve the equation for unknown K. Total body insulation (I_t) was calculated by formula 4 (Gagge and Gonzalez, 1996) with the assumption that a LCG creates a hybrid microclimate that falls somewhere between exposure to cold air and cold water (Webb 1970).

$$I_t = (T_{re} - \overline{T}_{sk})/M - (E_{res} + C_{res}) \tag{4}$$

Cooling efficiency (CE) was considered to be the ratio of cooling provided per unit of surface area perfused, as determined by Cheuvront *et al.* (2003). Specifically the values for CC were normalized to the maximum using formula 5, where the denominator is the % BSA perfused by the cooling garment and cooled for the entire experiment. The values for IC were normalized using formula 6, where the denominator is one-half of the %BSA perfused by the cooling garment representing cooling delivered for only 50% of the time. The relative CE of the IC scenario is thus represented by the ratio $(CE_{IC}/CE_{CC}) \times 100$.

$$CE_{CC} = (\Delta T_{reNC} - \Delta T_{reCC})/0.72 \tag{5}$$

$$CE_{IC} = (\Delta T_{reNC} - \Delta T_{reIC})/0.36 \tag{6}$$

Whole body sweating rate (M_s) was determined from Δ semi-nude body mass corrected for respiratory water loss and CO_2–O_2 exchange (Mitchell *et al.* 1972). The Physiological Strain Index (PSI) was determined using the originally published formula (Moran *et al.* 1998).

2.4. *Statistical analysis*

Data were analysed using commercial software (SigmaStat©, SPSS Science, Chicago, IL). A one-way (trial) ANOVA for repeated measures was performed for average mean body temperature, total change in core temperature, heart rate, skin temperature and PSI averaged over 75 min of exercise, as well as total sweating, and the components of the heat balance equation. A two-way (trial by time) ANOVA for repeated measures was performed on skin temperature, core temperature and heart rate. Tukey's honestly significant difference (HSD) post hoc test was applied when significant main or interaction effects were found. Statistical significance was set at $p < 0.05$. All data are reported as the mean $\pm$ SD.

3. Results

Table 1 summarizes calculated indices of average heat strain during the 75 min of exercise-heat exposure prior to hood and mask removal in the three experiments. Both cooling configurations lowered $\overline{T}_b$, heart rate and PSI compared to NC. $\overline{T}_{sk}$ during IC was significantly higher than CC and $\overline{T}_{sk}$ during NC was higher than IC and CC. There were lower sweating rates and a significant reduction in dehydration in both IC and CC compared to NC. The calculated PSI for IC and CC shown in table 1 were both in the low category and both significantly lower than NC.

A summary of the measured and calculated components of the heat balance equation used to estimate the mean cooling rate in each of the three conditions is provided in table 2. The rate of heat storage in IC and CC was significantly less than in NC. Calculated K represents conductive cooling by the LCG and indicates a significantly greater heat loss in IC and CC than in NC. Calculated R + C indicates the dry heat loss was significantly greater in NC than in both IC and CC, and was significantly greater in IC than CC.

Mean skin temperature across time is shown in figure 1(a) for all three conditions. By 10 min of exercise-heat stress, $\overline{T}_{sk}$ during NC (35.6 ± 0.4°C) was significantly higher than $\overline{T}_{sk}$ in both IC (33.1 ± 0.8°C) and CC (32.3 ± 0.6°C). Furthermore, by minute 20, $\overline{T}_{sk}$ in CC (32.4 ± 0.7°C) was significantly lower than in IC (33.8 ± 0.7°C) as well as NC (36.0 ± 0.4°C). Core temperature across time in the three conditions is shown in figure 1(b). By 50 min of exercise-heat stress, core temperature in NC (38.0 ± 0.4°C) was significantly higher than the core temperatures in both IC (37.4 ± 0.3°C) and CC (37.5 ± 0.3°C). Heart rate across time in the three conditions is shown in figure 2. By 20 min of exercise-heat stress, heart rate in NC ($118 \pm 6\,\mathrm{b \cdot min^{-1}}$) was significantly greater than in both IC ($106 \pm 8\,\mathrm{b \cdot min^{-1}}$) and CC ($105 \pm 10\,\mathrm{b \cdot min^{-1}}$).

Calculated I_t was significantly higher in CC ($0.025 \pm 0.005\ \mathrm{W \cdot m^{-2}}$) than in both IC ($0.0183 \pm 0.003\ \mathrm{W \cdot m^{-2}}$) and NC ($0.007 \pm 0.001\ \mathrm{W \cdot m^{-2}}$), and IC was significantly higher than NC. I_t and $\overline{T}_{sk}$ were negatively correlated ($r = -0.96$). The cooling efficiency for the IC scenario was 214 ± 69% relative to the 100% efficiency of the CC scenario.

4. Discussion

This study showed that IC during exercise with a simple on/off control sequence cooled the body as effectively as CC in subjects wearing personal protective equipment. These findings expand on previous observations that showed the efficacy of IC during rest after exercise (Muza *et al.* 1988, Bishop *et al.* 1991, Constable *et al.* 1994, Bomalaski *et al.* 1995). This study also showed that the impact of IC with a simple on/off control sequence is similar to that found with sequential cooling to distinct body regions during exercise (Cheuvront *et al.* 2003). The combination of environmental and exercise stress in the current study created significant heat strain as evidenced during the NC condition. It was clear that not only was core temperature significantly lower in both IC and CC than without cooling, but core temperature in both cooling experiments had nearly stabilized over the last 25 min of the experimental conditions (figure 1(b)). It was also evident that

Table 1. Indices of thermoregulatory strain averaged during the first 75 min of exercise-heat exposure (n = 4).

Condition	T_b (°C)	ΔT_{re} (°C)	$\overline{T}_{sk}$ (°C)	HR ($b \cdot min^{-1}$)	PSI	Ms ($g \cdot min^{-1}$)	Dehydration (%)
CC	36.41 ± 0.20^a	0.53 ± 0.32^a	32.63 ± 0.55^a	107 ± 9^a	2.2 ± 0.9^a	8.4 ± 1.2^a	0.8 ± 0.0^a
IC	36.58 ± 0.32^a	0.52 ± 0.17^a	33.68 ± 0.55^{ab}	110 ± 10^a	2.7 ± 0.6^a	8.8 ± 1.8^a	0.9 ± 0.1^a
NC	37.36 ± 0.41	1.57 ± 0.22	36.14 ± 0.35	139 ± 9	7.4 ± 0.3	17.7 ± 5.2	1.6 ± 0.4

T_b = mean body temperature; T_{re} = core temperature; T_{sk} = mean skin temperature; HR = heart rate; PSI = Physiological Strain Index; M_s = whole body sweating rate; CC = constant cooling; IC = intermittent cooling; NC = no cooling.
[a]Different from NC ($p < 0.05$).
[b]Different from CC ($p < 0.05$).

Table 2. Components of heat balance equation during 75 min of exercise-heat exposure ($W \cdot m^{-2}$) ($n = 4$).

Condition	M	W	R + C	C_{res}	E_{cl}	E_{res}	S	K
CC	211 ± 25	11 ± 0.47	7 ± 1.4^{a}	1.1 ± 0.1	28 ± 7	16 ± 1.9	3 ± 13^{a}	146 ± 4^{a}
IC	216 ± 17	11 ± 0.52	9 ± 1.4^{ab}	1.2 ± 0.1	28 ± 4	16 ± 1.3	9 ± 9^{a}	142 ± 7^{a}
NC	226 ± 12	11 ± 0.51	15 ± 0.9	1.2 ± 0.1	32 ± 5	17 ± 0.9	56 ± 8	94 ± 4

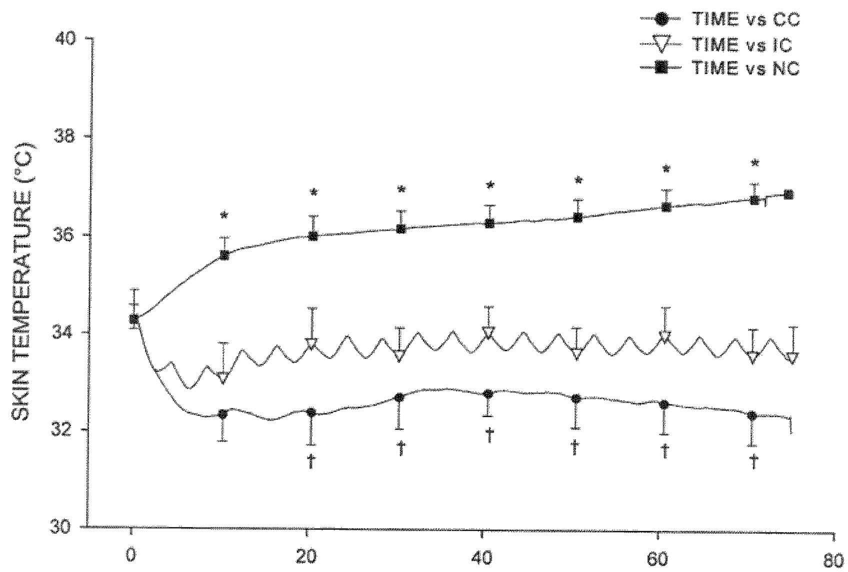
M = metabolic rate; W = external work rate; R + C = rate of dry (radiant + convective) heat exchange between clothed skin and the environment; C_{res} = rate of dry (convective) heat exchange via the respiratory tract; E_{cl} = rate of evaporative heat exchange between clothed skin and the environment; E_{res} = rate of latent (evaporative) heat exchange via the respiratory tract; S = rate of heat storage; K = microclimate cooling by conduction; CC = constant cooling; IC = intermittent cooling; NC = no cooling.
[a]Different from NC ($p < 0.05$).
[b]Different from CC ($p < 0.05$.

cardiovascular strain was minimized as long as skin temperature was maintained below 34°C in both IC and CC, as the heart rates stabilized after 10–30 min of exercise in these two conditions. It also appeared that the water-filled tubes in the LCG may have continued to absorb heat and maintained lower skin temperatures than NC even during the off phase of IC (figure 1(a)). The combination of the 21°C inlet temperature and 2-min on/off cycle time created an effective scenario for the IC to work. Longer on/off cycles or higher temperatures would likely result in the temperature difference between the skin and cooling garment narrowing, therefore diminishing heat transfer.

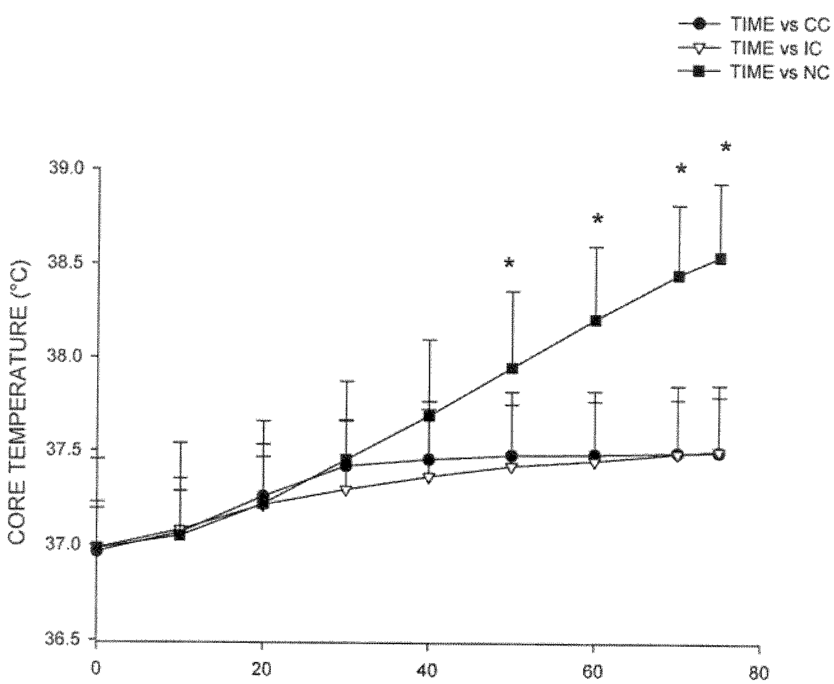
Microclimate cooling at 21°C lowered skin temperatures, increased heat transfer and reduced the rate of core temperature increase. Figure 1(a) showed that skin temperature fluctuated during the IC experiment in response to the water pump to the LCG being turned on and off. However, at all times during the IC experiment the mean skin temperature remained between 33 and 34°C, a temperature range likely to result in a release of vasoconstriction and possibly active vasodilation and to provide a core to skin temperature gradient favourable for heat loss (Johnson *et al.* 1976). Increasing inlet temperature could prevent this decrease in skin temperature. In the CC configuration, the mean skin temperature remained below 33°C throughout the experiment and was still decreasing at the end of the experiment, which might potentially slow the rate of heat loss during more prolonged work (Johnson *et al.* 1976). Recent work has indicated that for metabolic rates associated with most military activities inlet temperatures of 20–25°C are most appropriate (Xu *et al.* 2004). It is possible that increasing the temperature to 25°C with a decreased flow rate might result in higher skin temperatures under the cooling garment. Over the 75-min time course of the current experiments with inlet temperature at 21°C, the skin temperature in both IC and CC scenarios allowed for a constant 3–4°C T_{re}–$\bar{T}_{sk}$ difference, favouring heat transfer from core to skin to the LCG. This might not hold true with increased inlet temperatures and lower flow rates.

IC also proved to be more efficient than CC at the metabolic rate and cooling scenarios used. The average core temperature increased similarly in both the IC and CC tests even though cooling was provided only one-half the time in IC. This showed the approach to be over twice as efficient as CC, possibly because of the release of vasoconstriction with skin temperatures above 33°C. This cooling efficiency is similar to that reported by Cheuvront *et al.* (2003) in the 50% cooling scenarios, but was achieved with a less complicated cooling scheme.

The IC and CC scenarios significantly reduced cardiovascular strain relative to NC as shown by lower heart rates after 20 min of the exercise-heat exposure. Higher heart rates



(a)



(b)

Figure 1(a). Mean ± SD skin temperature during the 75 min of exercise-heat stress in all three conditions before hood and mask were removed (n = 4). *Significantly higher than constant cooling (CC) and intermittent cooling (IC) ($p < 0.05$). †Significantly lower than IC ($p < 0.05$). Figure 1(b). Mean ± SD core temperature during the 75 min of exercise-heat stress in all three conditions before hood and mask were removed (n = 4). *Significantly greater than CC and IC ($p < 0.05$).

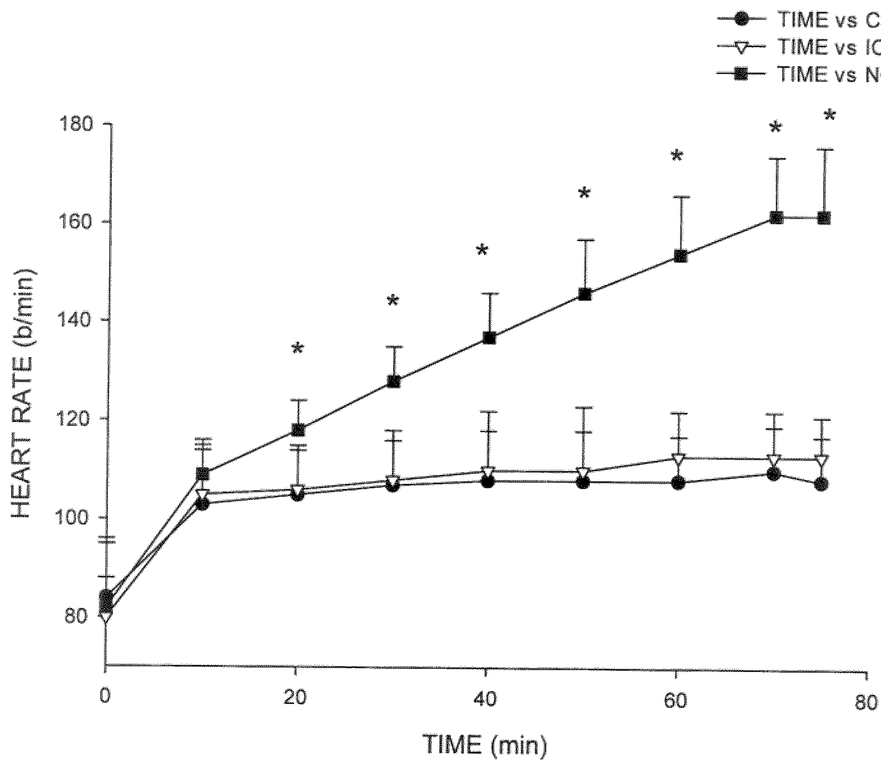


Figure 2. Mean ± SD heart rate during the 75 min of exercise-heat stress in all three conditions before hood and mask were removed (n = 4). *Significantly greater than constant cooling and intermittent cooling ($p < 0.05$).

in NC likely resulted from increased skin blood flow to the increasingly warmer skin as an attempt to dissipate heat from the body to the environment. Even though mean skin temperature in IC was up to 2°C warmer than in CC, body heat was still transferred to the cooling garment. Additionally, both IC and CC resulted in lower sweating rates and, subsequently, less dehydration relative to NC, further reducing cardiovascular strain.

5. Conclusion

In the current study, it was concluded that IC delivered at 21°C, 1.2 litres $\cdot$ min^{-1} to a whole body LCG in a pattern of 2 min on and 2 min off reduced heat strain equivalent to continuous cooling to the same LCG of exercising men dressed in US Army chemical protective clothing. It can also be concluded that IC allows for the maintenance of moderate peripheral cutaneous vasodilation compared to cutaneous vasoconstriction, which occurs if the skin is overcooled. The findings suggest that even when not being actively perfused, the LCG may passively absorb heat, favouring heat transfer from the body core.

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